

2dF Spectroscopy of M104 Globular Clusters

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Abstract. We present preliminary results of 2dF spectroscopy of globular clusters in The Sombbrero (M104). We find 56 new clusters, and compile a total sample of 103 velocities combined with previous data. Our 2dF data extend out to 20 arcmin radius (~ 50 kpc), much further than previous studies. In the combined sample, we tentatively find a steep drop in the velocity dispersion with radius, which might possibly indicate a truncated halo. There is no obvious solid-body rotation over all radii, but separate fits for those clusters inside and outside 25 kpc radius show tantalizing evidence for counter-rotation. The projected mass estimator with isotropic orbits yields an M104 mass of $1.2 \times 10^{12} M_{\odot}$ inside 50 kpc, and a $(M/L)_B = 30$: solid evidence for a dark matter halo in this galaxy.

1 Introduction

Wide-field spectroscopy of globular clusters (GCs) is an excellent way to study galactic mass distributions at large radii, and to learn more about the angular momentum content of early-type galaxies (e.g. Zepf, this workshop). GC spectra also provide cluster ages and metallicities, which are a further means to distinguish between various models for GC and galaxy formation.

2 Observations

We have used the 2dF¹ multi-fibre spectrograph on the AAT to obtain spectra of GC candidates in M104. 2dF, with a two degree f.o.v. and 400 fibres, is very well-suited to wide-field studies of globular clusters in nearby galaxies. GC candidates were obtained from KPNO Mosaic CCD BVR imaging over a 34×34 arcmin field (Rhode & Zepf 2002, in preparation). After removal of extended background galaxies and objects with colours outside the range of known GCs, we have a list of 585 candidates with $19.0 < V < 21.5$.

In April 2002, we obtained 2dF spectra for 200 of these candidates in 8 hours of AAT time. We also obtained spectra for several radial velocity and Lick standard stars. The `2dfdr` package was used to reduce the spectra, and the IRAF/FXCOR package used to obtain velocities via cross-correlation. 163 objects turned out to have spectra with enough S/N to yield reliable velocities. Of these, 56 had $500 < V < 1500$ km/sec, which we take to be genuine M104 GCs.

¹ see www.aao.gov.au/2df

Combined with previous WHT [1] and Keck [7] data, we have a total sample of 103 M104 GCs. **Figure 1** shows the location of the M104 clusters from the 3 studies; it can be seen that our 2dF data extend out to ~ 20 arcmin radius (50 kpc for a distance of 9 Mpc; [4]), much further out than previous studies.

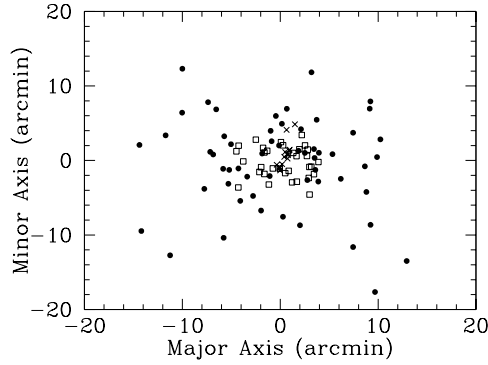


Fig. 1. Location of M104 GCs. Solid points: new 2dF GCs (April 2002); Open squares: WHT/LDSS-2 GCs [1]; Crosses: Keck GCs [7]. Note that the 2dF GCs extend to a radius of ~ 20 arcmin (50 kpc)

3 Results

3.1 Velocity Dispersion Profile

Figure 2a plots velocity vs. galactocentric radius, and shows that the velocity dispersion decreases very quickly with radius. To quantify this, we have computed smoothed velocity and velocity dispersion profiles with a gaussian kernel of $\sigma = 100$ arcsec (see [9] for more details on the technique). **Figure 2b** shows that the velocity dispersion drops from ~ 225 km/sec at the galaxy center to ~ 125 km/sec at 13 arcmin (32 kpc) radius. Such a steep drop might indicate a truncated dark matter halo (but see Section 3.4).

3.2 Rotation

In **Figure 3** we plot velocity vs. azimuthal angle for the combined cluster sample, where $\theta = 0, 180$ corresponds to the major axis. There is no obvious rotation (i.e. no systematic variation of velocity with position angle). This is confirmed by nonlinear least squares fits for solid body rotation:

$$V = V_{sys} + V_{rot} \cos(\theta - \theta_0),$$

where V_{sys} is the systematic velocity, V_{rot} is the rotation amplitude, and θ_0 is the line of nodes. The best-fit rotation is ~ 60 km/sec, but Monte Carlo simulations

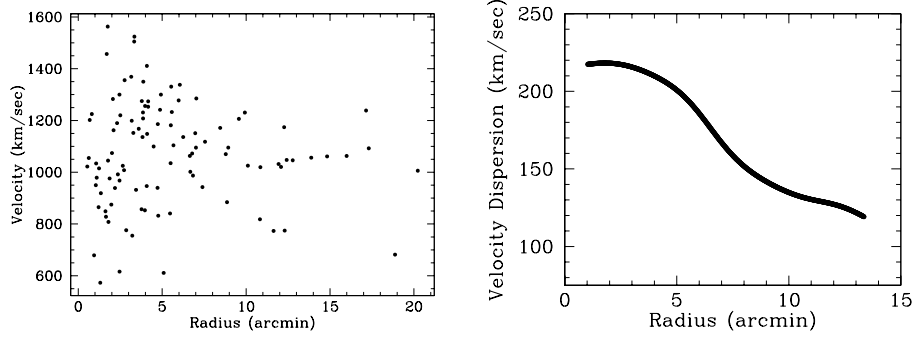


Fig. 2. (2a) (left): Velocity vs. galactocentric radius for 103 confirmed M104 GCs. (2b) (right): Smoothed velocity dispersion profile, quantifying the steep drop in velocity dispersion with radius.

show that this is not significant (100 random datasets were run through the least-squares code, with 72% of these having a rotation amplitude of 60 km/sec or higher).

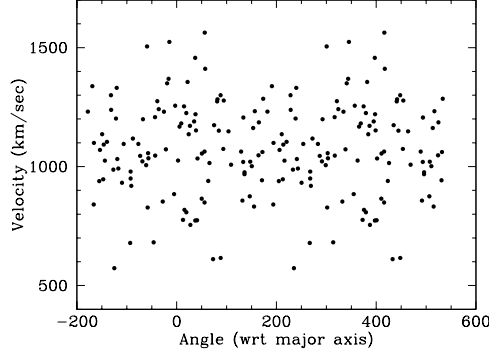


Fig. 3. Velocity vs azimuthal angle for M104 GCs (folded), showing lack of rotation in combined sample.

So there appears to be no significant rotation in the combined sample over all radii, which is in agreement with the finding of Held et al. (this workshop). When divided by colour/metallicity, there is still no significant rotation in either subpopulation. However, we have investigated further by splitting up the clusters into an ‘outer’ (16 GCs) and an ‘inner’ (87 GCs) sample, divided at a radius of 25 kpc. **Figure 4** shows that the inner and outer GCs may each have rotation, and most interestingly, of opposite sign. The possible rotation of the inner clusters is in the same direction as the stellar component (e.g. [5]), while the outer clusters would be rotating in the opposite direction. This possible counter-rotation is

extremely interesting, and may indicate a different origin for the inner and outer GCs— might the outer GCs have been accreted from another galaxy? Supporting evidence for a past interaction involving M104 comes from the tidal features seen by [8].

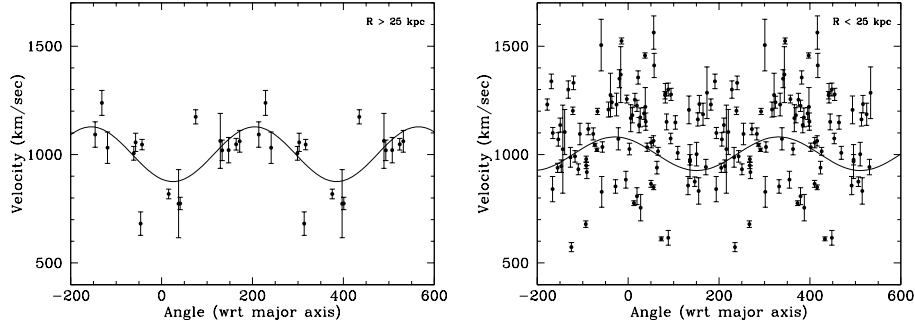


Fig. 4. Same as Figure 3, but now split by radius. **Left:** (16) GCs with $R > 25$ kpc, with a rotation amplitude of 125 km/sec. **Right:** (87) GCs with $R < 25$ kpc, with a rotation amplitude of 80 km/sec. Note that the two samples are approximately 180 degrees out of phase, as expected if they are counter-rotating.

3.3 Comparison with PNe

Freeman et al. (unpublished) have velocities for ~ 250 planetary nebulae (PNe) out to 20 kpc radius. They find a constant velocity dispersion of ~ 220 km/sec, and approximately constant rotation of ~ 100 km/sec out to 4 kpc; beyond 4 kpc, there is negligible rotation. There may thus be differences in the kinematics of the GCs and PNe, but the comparison is not straightforward, because the two components cover different radial ranges.

3.4 Mass of M104

We have used the Projected Mass Estimator [6] to get a crude determination of the mass of M104 (to within a factor of a few). Assuming isotropic orbits and an extended mass distribution, we find a mass of $M = 1.2 \times 10^{12} M_{\odot}$ within a radius of 20 arcmin (50 kpc). From [2], the total integrated magnitude out to this radius is $B=8.7$, and for a distance of 9 Mpc, this gives $(M/L)_B = 30$ out to 50 kpc. This is solid evidence for a dark matter halo in M104. Note that M104 does not have extended diffuse X-ray emission, and therefore dynamical probes such as GCs and PNe are the only way to determine the halo mass in this galaxy. With larger samples of GCs, we can improve on the mass determination by using the velocity dispersion and density profiles of the GCs and the Jeans equation.

4 Conclusions

This work demonstrates the power of wide-field, multi-object spectroscopy in the study of GC kinematics and galactic dark matter at large radius. It is interesting to compare our preliminary GC kinematics with those of elliptical galaxies. The possible rotation seen in the inner and outer M104 GCs is similar in amplitude to that found in M49 [9] and M87 [3]. There is no evidence for counter-rotation of GCs in M49, but the rotation axis of the M87 metal-poor clusters flips from the minor axis to the major axis within 15 kpc radius ([3]). Richtler et al (this workshop) find little rotation in the NGC 1399 GCs, except perhaps at large radius. The possible counter-rotation of the outer GCs that we have found is very intriguing, and it may be that these GCs were accreted during a past interaction. Further velocities are clearly required. Hanes, Bridges, Harris, and Gebhardt have CFHT/MOS spectra for several hundred M104 GCs, and we have applied for further 2dF time, so the prospects for increasing the sample size are good. In a related project, Beasley, Bridges, Forbes, Harris, Harris, Mackie, and Peng have applied for 2dF time to carry out a detailed study of the Centaurus A GCS. Multi-fibre spectroscopy on 4m telescopes is quite complementary to programmes being carried out on 8m telescopes (e.g. the Gemini/GMOS programme in which TJB and SEZ are involved), which naturally focus on obtaining cluster ages and abundances over smaller fields. However, there will be soon be many multi-fibre spectrographs on 6-8m telescopes, with several hundred fibres over fields of 0.5–1 deg (MMT/Hectospec, VLT/FLAMES, Subaru/FMOS), and the future is looking bright indeed.

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